Energy on Demand

FINDING effective means for harnessing power from energy sources has become a hot research area in recent years, spurred by the nation's ever-increasing demand for more power and the need to reduce consumption and reliance on fossil fuels. Renewable energy sources, such as solar and wind, could help reduce the carbon footprint. For centuries, hydropower has been the most productive form of renewable energy, and geothermal power has also been tapped to generate electricity to help meet consumer demand.

Unfortunately, hydro and geothermal sources are not always located in areas that make it easy to integrate them into the electric grid. Solar and wind power, on the other hand, may increase the possible locations where energy might be produced, but their energy production is intermittent—not always available or predictable. This quality makes it difficult for utility companies to effectively rely on these sources. In fact, utility companies need to provide an equal amount of backup power, often not from renewable sources, to ensure energy availability.

Storing energy from wind, solar, and conventional sources when conditions are favorable, so that it can then be used at a later time, such as when demand is high, may be the answer to this grid-integration problem. A novel electromechanical battery (EMB) designed by Livermore has the potential to provide maximum bulk storage of energy produced from a variety of sources with minimal energy loss. As part of a Cooperative Research and Development Agreement, Laboratory scientists are working with EMB Energy, Inc., which has engaged several other commercial partners including Arnold Magnetics Technologies Corporation, ATK, and Williams International, to build large, modular EMB storage systems capable of addressing the huge power-leveling requirements of the grid.

Livermore has had several decades of experience developing EMBs. Initial systems were designed for specialized, high-power applications where pulses of electricity were needed to ride through short interruptions in electrical power. "This technology was beneficial for facilities such as hospitals that cannot afford downtime in their power supply," says Laboratory physicist Richard Post, who has led EMB research efforts. "However, previous versions of the technology had energy losses that were too great for the device to be sufficient for energy storage applications, where the required storage time is many hours."

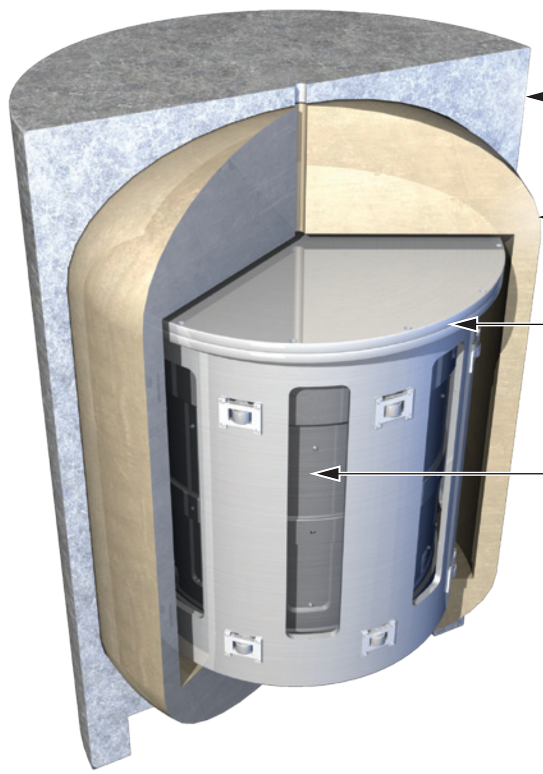
With several innovative technologies integrated into one, the newest EMB iteration is predicted to store energy for 6 to 8 hours, while releasing it over periods of 1 to 4 hours. In addition, unlike previous EMBs, which can waste 20 to 30 percent of their energy through internal losses, the newest EMBs have only a projected 5-percent energy loss.

With a highly aggressive schedule, this government–private industry partnership plans to build bulk storage EMBs for commercial deployment in 2012. The team will manufacture several EMB prototype devices, the final model being a 250-kilowatt-hour EMB. Ultimately, several hundred batteries will be configured in an underground array to capture, store, and dispatch energy gathered from various energy sources, including solar and wind. Once in the field, these novel systems will offer an energy boost to the grid, translating into savings for both utility companies and consumers.

Energy on the Fly

During Post's nearly 60-year career at Livermore, he has been the mastermind behind many inventions, including three distinct devices that have come together to create the bulk storage EMBs. A flywheel made from low-density, high-strength composite materials stores rotational energy for the system. A novel electrostatic generator–motor both powers up and discharges energy from the EMB system with the proverbial flip of a switch. And, tapping into his expertise in magnetic fusion, Post developed "passive" magnetic bearings that stabilize the EMB system with no mechanical friction energy losses. All the components are encased in a sealed, cylindrical vacuum vessel, where they work in concert to store and extract electricity with high efficiency.

In the 1970s, Post was one of the first to point out that a material's strength per unit weight is what dictates its kinetic energy storage capacity. "The idea for using high-strength, low-density composite materials instead of high-density metals to create flywheels grew out of working with my son Steve on an EMB for electric vehicles," says Post. Together, they wrote an article entitled "Flywheels" for *Scientific American* that discussed approaches to designing flywheels using high-strength composites. At that time, flywheels were typically fabricated from metals such as steel because at a given rotational speed the more mass a material has, the more kinetic energy it can store. However, in the *Scientific American* article, they showed that a high-strength, lower

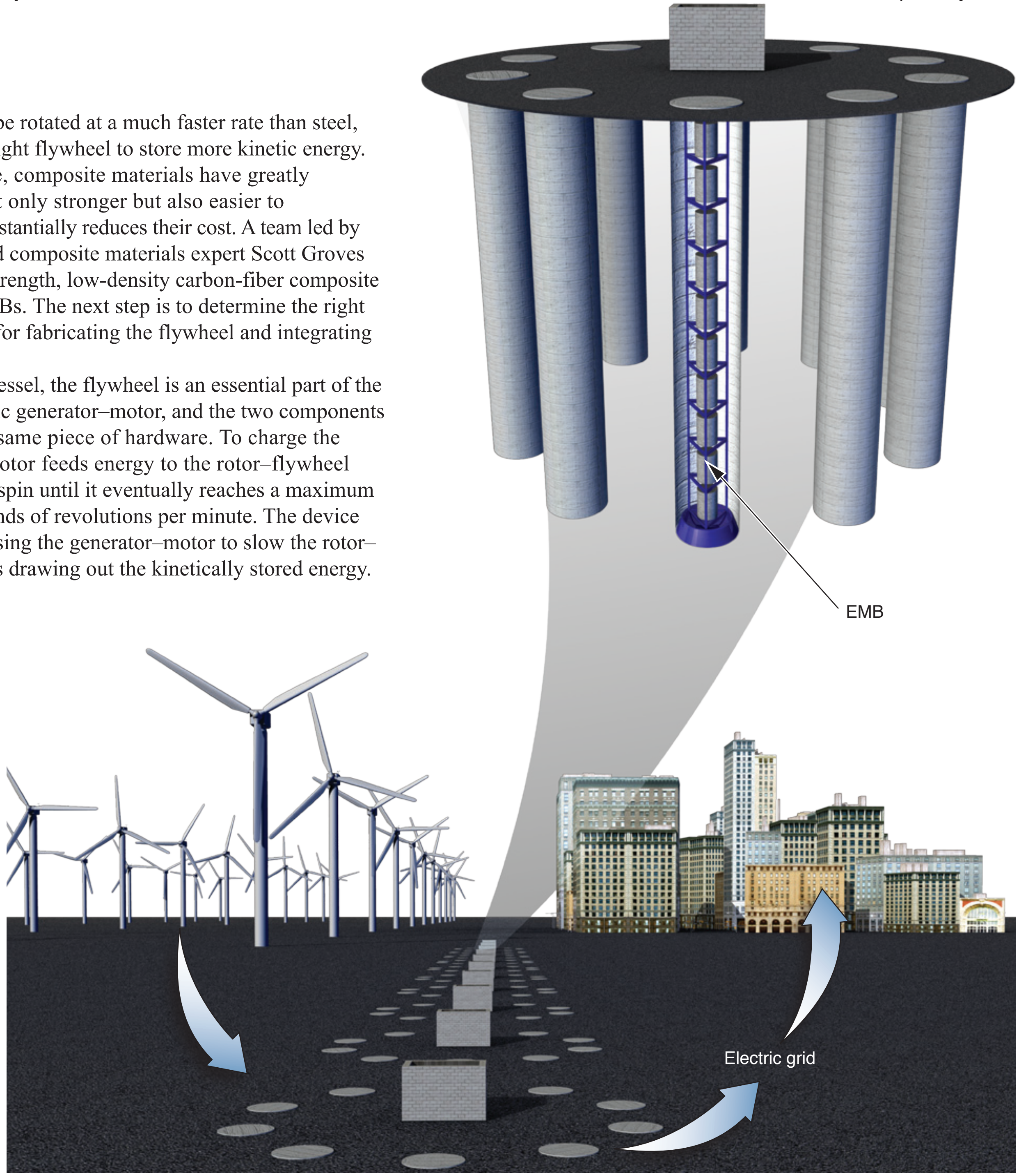


Livermore's electromechanical battery (EMB) unit consists of a vacuum vessel that houses an assembly containing a flywheel made from composite fiber material, an electrostatic generator–motor, and passive magnetic bearings, among other essential components. (Rendering by Kwei-Yu Chu.)

density material could be rotated at a much faster rate than steel, enabling the lighter weight flywheel to store more kinetic energy.

Over the last decade, composite materials have greatly advanced. They are not only stronger but also easier to manufacture, which substantially reduces their cost. A team led by Livermore engineer and composite materials expert Scott Groves has developed a high-strength, low-density carbon-fiber composite perfectly suited for EMBs. The next step is to determine the right material combinations for fabricating the flywheel and integrating it into the device.

Inside the vacuum vessel, the flywheel is an essential part of the rotor for the electrostatic generator–motor, and the two components are integrated into the same piece of hardware. To charge the EMB, the generator–motor feeds energy to the rotor–flywheel assembly, causing it to spin until it eventually reaches a maximum speed of tens of thousands of revolutions per minute. The device is then discharged by using the generator–motor to slow the rotor–flywheel assembly, thus drawing out the kinetically stored energy.



Several hundred EMBs will be configured in an underground array to capture, store, and dispatch energy from various energy sources into the electric grid. The power supplied by these devices could help utilities more easily meet consumer demand during peak usage. (Rendering by Kwei-Yu Chu.)

Unlike the more common flywheel-battery storage systems that use electromagnetic generator–motors, the electrostatic version has virtually no internal losses. Also, instead of using so-called "active" magnetic bearings that require electrical power, permanent "passive" magnetic bearings are used to dynamically stabilize the system without the need for complicated sensors, control circuits, and electromagnets.

Placed in a configuration known as a Halbach array, invented by the late Klaus Halbach of Lawrence Berkeley National Laboratory, the magnets are arranged to create a periodic magnetic field that is alternately vertical and horizontal. This arrangement concentrates the field on one side, while canceling it on the other. The passive magnetic bearings have very low losses, allowing the rotor–flywheel to continuously spin with minimal energy loss. All together, the passive magnetic bearings, electrostatic generator–motor, and composite flywheel make up a system that suffers far less energy loss and provides greater storage-time capability compared to standard EMB systems that contain electromagnetic or mechanical bearings and magnetostatic generator–motors.

Stepping Stones

Livermore researchers have successfully demonstrated prototypes of the electrostatic generator–motor with a small startup company and the passive magnetic bearings with Arnold Magnetics. Ultimately, the team will design several EMB prototypes, each serving as a springboard to the next, with the first one scheduled for completion this summer. Bob Yamamoto, the project's principal investigator, says, "The initial proof-of-concept will be a 5-kilowatt-hour battery about the size of a coffee urn that will demonstrate all the disparate parts fully integrated into a single homogeneous operational unit."

A 25-kilowatt-hour battery built in collaboration with Livermore's industrial partners will mimic the final product design but at a reduced scale. "This smaller version of the 250-kilowatt-hour battery will measure 2 meters in diameter and be about 30 centimeters tall," says Yamamoto. "The production-ready battery will be about 1.8 to 2.4 meters tall."

The commercial EMBs are expected to have decades of lifetime, as opposed to more common electrochemical batteries that in many cases must be replaced about every two years. Post points out that the new product should also be much less expensive to produce, and its potential safety hazards are well accounted for and easily controlled, unlike the more volatile, explosive nature of some electrochemical batteries.

As a result of EMB's cost-effectiveness, long life, and less hazardous nature, the device promises to be an enabling technology for the nation's smart grid, which is expected to be fully deployed within the next five years. The smart grid will use a wide array of technologies to dynamically respond to changes in grid conditions. "The timing is perfect for this technology," says Yamamoto. "Right now, the nation is focused on delivering cost-effective solutions for producing and storing energy. The new EMB technology melds a variety of technologies Dick has developed over the last several decades to create a unique, low-cost bulk energy storage technology that meets the nation's needs."

The Tip of the Iceberg

At the heart of EMB's success is the special relationship between the scientists, the Laboratory's Industrial Partnerships Office, and the commercial partners. "Through these collaborations, we have built a series of low-cost prototypes, at relatively low risk to our partnering companies, so we could prove each innovation separately," says Annemarie Meike, a Livermore business development executive who promotes and manages EMB technology transfer to private industry. "The communication exchange between innovators and manufacturers during this time has been invaluable, leading to robust relationships that will carry forward for this and other applications."

The current Cooperative Research and Development Agreement covers large-scale EMBs for bulk energy storage applications, but the EMB technology can be licensed for other purposes. "The device could be adapted for use as a power source for individual homes, which would be particularly useful in rural environments," says Post. Some day, EMB technology may even be used to power entire communities, independent of the grid. For now, EMBs are well on their way to providing a much needed resource for storing energy from intermittent renewable energy sources, propelling the nation toward more environmentally benign energy sources and a "greener" way of life.

—Caryn Meissner

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